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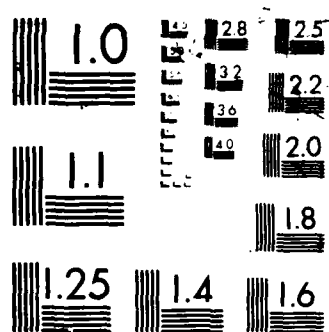
NDP (NEUTRON DEPTH PROFILING) EVALUATIONS OF
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NDP Evaluations of Boron-Implanted Compound Semiconductors

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<p>This report describes recent neutron depth profiling (NDP) experiments on the distribution of implanted boron in several semiconductors. The objectives are to compare the boron profiles for different materials that had been simultaneously implanted and to assess the effects of annealing treatments that were used to remove implant damage and electrically activate the boron.</p> <p><i>Key words:</i></p>					
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NDP EVALUATIONS OF BORON-IMPLANTED COMPOUND SEMICONDUCTORS

Ion implantation technology is widely used to fabricate optoelectronic devices from compound semiconductors. Applications of boron ion implants include the production of n-p junctions in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ for infrared photodiode detectors and the isolation of electrically active regions in GaAs microwave devices. While the behavior of boron implants in silicon has been extensively studied, rather limited information is available on the distribution and behavior of boron implants in compound semiconductors¹. This report describes recent neutron depth profiling (NDP) experiments on the distribution of implanted boron in several semiconductors. The objectives are to compare the boron profiles for different materials that had been simultaneously implanted, and to assess the effects of annealing treatments that were used to remove implant damage and electrically activate the boron.

Representative profiles of the as-implanted boron-10 isotopes in (100)-Si, (100)-GaAs, (111)-CdTe, and (100)- $\text{Hg}_{0.68}\text{Cd}_{0.32}\text{Te}$ are presented in Fig.

1. These results have been obtained by NDP measurements² on the 20-MW research reactor at the National Bureau of Standards. All four samples had been simultaneously doubly implanted with boron ($^{10}\text{B}^+$) ions at 50 keV and 100 keV energies to doses of 5×10^{15} ions/cm² and 1×10^{16} ions/cm², respectively. The boron profiles in Fig. 2 exhibited substantial differences among the various materials. While some distortions (i.e., boron profiles that extend well above the sample surfaces) of the NDP results occur for CdTe and $\text{Hg}_{0.68}\text{Cd}_{0.32}\text{Te}$ due to a "pulse pile-up" effect² caused by electrons emitted from the Cd, Hg, and Te constituents, much of these differences correspond to the nature of the ion stopping properties of each semiconductor. Further insights on the behavior of the boron implants were obtained by performing Monte Carlo calculations of the boron ion projected ranges with the TRIM-86 version of the analysis method described by Ziegler, et al.³ An example of the calculated boron profile that was generated by an appropriate summation of the 50 keV and 100 keV boron ion ranges in GaAs is included in Fig. 1. The good agreement between the NDP measurement and model

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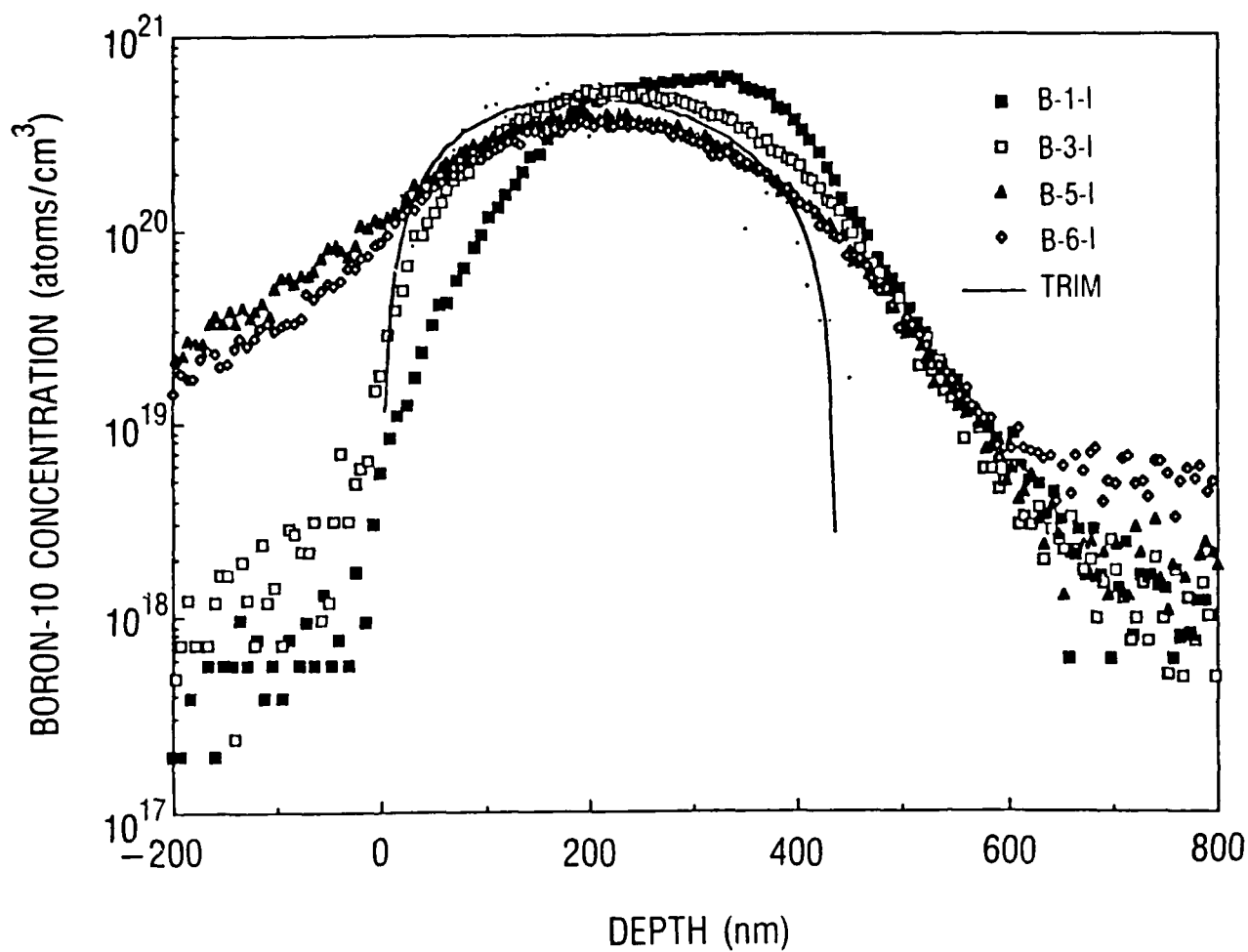


Fig. 1. Boron-10 NDP Profiles for Ion-implanted Silicon (B-1-I), GaAs (B-3-I), CdTe (B-6-I), and $\text{Hg}_{0.68}\text{Cd}_{0.32}\text{Te}$ (B-5-I). The solid curve is the theoretical profile for GaAs from the TRIM-86 Monte Carlo projected range calculations.

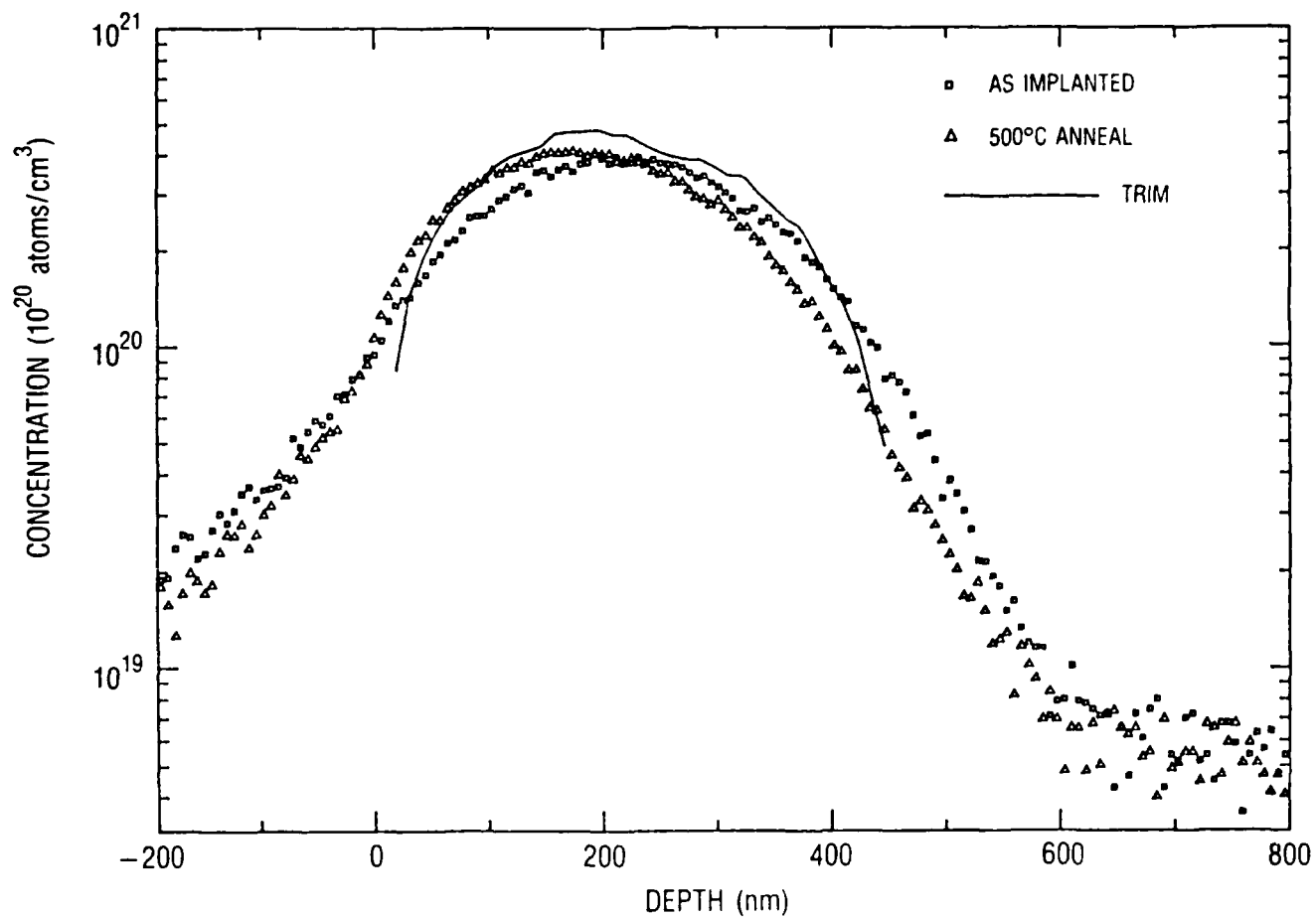


Fig. 2. Boron NBP Profiles from CdTe Crystals as Implanted and After 1 hr 499°C Anneal Under Vacuum. The solid curve is the profile from the TRIM-86 calculations for as-implanted conditions.

profile is apparent. Similar comparisons have been made for the other materials and various implant conditions. A second example is given in Fig. 2 for the 50 keV//100 keV double implants into CdTe. While the pulse pile-up effect in the NDP profile for ^{10}B in CdTe decreases the quantitative agreement with the TRIM-86 model profile, the general features, such as a skewing of the boron distribution towards the surfaces, are quite consistent. Enhanced backscattering of the boron ions during implantation occurs as the masses of the target atoms increase.

The influence of anneals on the boron atom distributions has also been examined. The effects on the boron NDP profiles in CdTe are shown in Fig. 2. The 499°C anneal in an evacuated, closed quartz tube caused the entire profile to shift toward the surface, but without any substantial change in the shape of the profile. Furthermore, the NDP measurements indicated that less than 4% of the initially implanted boron had been lost from the sample after the anneal. These results suggest that an approximately 25-nm thick layer of material from the CdTe surface had evaporated during the anneal, but little diffusion of the implanted boron atoms had occurred. NDP measurements also indicated very little diffusion of boron in either GaAs or $\text{Hg}_{0.68}\text{Cd}_{0.32}\text{Te}$ after anneals at 850°C or 400°C, respectively. However, substantial diffusion of boron was evident in the silicon samples after 1000°C anneals.

In summary, neutron depth profiling has been found to be a valuable non-destructive method to quantitatively monitor the boron distributions in several semiconductors. Some of the requirements and limitations of this technique have been identified through detailed comparisons with calculated boron profiles from the TRIM Monte Carlo model.

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